Measuring CENNS in the Low Energy Neutrino Source at Fermilab

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The Coherent Elastic Neutral-Current Neutrino Nucleus Scattering (CENNS) is known as a very important process in studies of supernova explosion, neutrino magnetic moment, tests of the standard model weak mixing angles, searches for sterile neutrinos, z-prime bosons, and non-standard interactions of neutrinos [1-5]. Moreover, the CENNS by solar and atmospheric neutrinos would be irreducible backgrounds in future direct searches for dark matter [6]. The CENNS, however, has never been observed since its first theoretical prediction in 1974 [7], owing to the need to detect rather intimidating low-rate and low-energy signals. The condition of coherence requires sufficiently small momentum transfer to the nucleon so that the waves of off-scattered nucleons in the nucleus are all in phase, thus summing coherently. While interactions of neutrinos with energy at the MeV to GeV-scale will have CENNS components, neutrinos with energies less than ~50 MeV largely fulfill the coherence condition in most target materials with typical nuclear recoil energy of only tens of keV. The elastic neutral-current interaction, in particular, leaves no observable signature other than this very low-energy nuclear recoil, the likes of which might now be observed given innovations in dark matter detector technology [8-13].

We realized that the requisite low-energy neutrinos can be obtained from the neutrinos produced far-off-axis (> 45 degrees) of the Fermilab Booster Neutrino Beam (BNB). The BNB source has suppressed kaon production from the relatively low-energy, 8 GeV (8~32 kW) proton beam on the target. Consequently, pion-decay and subsequent muon-decay processes are the dominant sources of neutrinos. The expected neutrino flux is about $5\times10^5/\mathrm{cm}^2/\mathrm{s}$ at a distance of 20 m from the target (at 32 kW). At the far-off-axis area, the detector can be placed close enough to the target to gain an inverse-distance-squared increase of the neutrino flux. The pulsed structure of the neutrino beam also lends a substantial advantage in background reduction (~10^{-6}) against steady-state cosmogenic and radiogenic backgrounds.

A ton-scale, single-phase, low-energy threshold liquid argon detector has been conceptualized to measure the CENNS. The detector will utilize pulse-shape discrimination of scintillation light between nuclear recoil and electron recoil interactions in the liquid argon to identify and discriminate CENNS interactions from background events internal to the target. Electromagnetic and neutron backgrounds from external sources will be rejected using the standard active and passive shielding methods together with self-shielding and fiducialization. In early 2012, we measured the beam-induced neutron background at the Booster Beam target building, first using a commercial neutron detector and then the SciBath neutral particle detector. The preliminary results indicate that the beam-induced neutron flux and energy spectrum is at a manageable level for the CENNS experiment [14] and studies are underway to define the external shielding required to attenuate cosmic rays and, in particular, muon-induced neutron backgrounds at the FNAL site. A substantial collaboration has been formed with design work and prototyping underway to realize a ton-scale CENNS detector, lending from the significant developments and progress using liquid argon as a low-energy threshold detector.

The successful experimental results of CENNS and associated background measurements in the energy range of solar and atmospheric neutrinos will be immediately useful for dark matter search experiments. The far-off-axis neutrino source, incorporated into Fermilab's future Project-X program [15], may provide a well-defined and intense low-energy neutrino source. Such a source, in concert with new capabilities for low-energy threshold detectors using liquid argon will open unexplored avenues to investigate low energy neutrinos.

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